Head injury prevention in alpine skiing and snowboarding

Critical review of literature and analysis of NZ snow sports injury epidemiology – Technical report for the Coroner's office

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Objective
To inform the Coroner's inquest into alpine skiing and snowboarding fatalities regarding the magnitude of the head injury problem in alpine skiing and snowboarding in New Zealand, and evidence for helmets as an injury prevention strategy.

Methods
Searches of Pubmed, Medline, and SportDiscus literature databases were performed for studies related to alpine skiing injuries published in English. The computer databases provided access to sports-oriented and biomedical journals, serial publications, books, theses, conference papers and related research published since the inception of the International Society of Skiing Safety in 1974. Literature was extracted by one systematic reviewer using key words alpine skiing, snowboarding, protective equipment, helmets, epidemiology, head injury, neck injury, fatality, and death.

ACC injury data

Injury data including free text descriptors of mechanics of injury were obtained for snow sport ACC claims from 1 January 2000 to 31 December 2008 to enable comparisons with international data reported in the literature. Injuries were categorised by diagnosis (e.g., fracture/dislocation, soft tissue injury) for alpine skiing and snowboarding.

NID injury data

Injury data were also obtained for snow sport injuries during 2005 to 2009 from the National Incident data base (NID) utilised by all NZ commercial ski areas and managed by the NZ Mountain Safety Council.

Results

Helmet protection biomechanics – Helmets are designed to limit linear acceleration to not more than 300 g following a 2.0 m drop onto a steel surface (translating to 27.7 km/h). Scher et al [1] conducted simulation impact testing of ski/snowboard helmets using an anthropomorphic test device in a manner replicating the average speed (43.5 mph) of a snowboarder falling with and without a helmet onto a snow covered intermediate ski run at Mammoth Mountain, California. Falls in soft snow with or without a helmet did not produce the g-loads likely to cause head injury as energy dissipated with disruption of the snow surface area. In contrast helmet use when the snow surface was icy resulted in significant dissipation of energy through deformation of the helmet. Helmet use in icy snow conditions was estimated to reduce the probability of a skull fracture and severe brain injury from approximately 80% to 20%. At 30 kph with an opposite-edge fall a typical snowboarder would have ample reaction time to self protect (approximately 400 ms) and roll forward with a shoulder or fall on an outstretched hand(s). In simulated collision of a snowboarder colliding with a fixed object at 30 kmph the helmet reduced the head accelerations by more than a factor of two to 333 g's; however, the probability of skull fracture and severe brain injury remained at 99.9% in the helmeted condition. Protection by helmet wear declines over 300 g's.[1] Helmets have reduced head injury such as abrasions, lacerations, and mild concussion. [2] Average on slope speeds of children using speed cameras on intermediate slopes were 18.7 kph [3]. Paediatric simulation impact testing the potential for a head injury with or without a helmet was undertaken based on the average speed. The potential for head injury in a collision with an object was 47%, and collision with another skier was 69%. Wearing a helmet reduced the probability of a traumatic brain injury in the paediatric population by 0.2% or less. The forward motion of the head and inertial effect on neck loading after the body collided with an object were no different with or without a helmet. There was no evidence that helmets increased the risk of neck injury in case control studies [4, 5]. Terrain park users were more likely to suffer a head injury with loss of consciousness than skiers, regardless of helmet use ($P < 0.5$) [6].

Helmet protective capacity in fatalities - In a review of the incidence of fatalities in the USA [2, 7] from 1991 to 2005 there was no evidence of decline in fatalities with the increase in helmet usage. The rate of death per million skier/boarder days in the US was 0.02% for skiers and 0.07% for snowboarders. Most fatalities were contributed to collision with an object.

Helmet standards - Helmets for alpine skiers and snowboarders should comply with the European standard EN 1077 [8], American standard F 2040 [9] or American Snell RS-98 [10]. EN 1077 comprises protection class A and class B. Class A helmets cover a larger part of the head and have a higher degree of penetration resistance compared to class B helmets which have detachable ear coverings, are slightly less restrictive, accommodate more ventilation, and may be more comfortable without sacrificing too much in protection.

Helmet use - Italy and Croatia introduced mandatory helmet use for children aged 14 years and younger in 2005. After the high profile manslaughter verdict of German politician Dieter Althaus who skied with a helmet, but did not comply with the slope rules, and collided and killed a female adult skier who was not wearing helmet, Austria made helmet use compulsory for children aged less than 16 years in 2010 [11]. Since the death of actress Natasha Richardson at Mont Tremblant Quebec in 2009, Intrawest has strongly recommended helmet use in all nine of their North American ski resorts. Helmets are mandatory for children and teenagers enrolled in Intrawest ski or snowboard programmes. For countries where helmet use is not mandatory, helmet use has been increasing. For 2009, Switzerland reported 65% of skiers and snowboarders wore helmets with a 90% reach for children under 17 years of age. In France in 2008, 90% of children to the age of 11 years wore helmets [12].

Helmet usage in the total population recreating at New Zealand ski areas has not yet been determined. The lack of this data prevents determination of the actual impact of wearing helmets in reducing head injuries in skiers and snow boarders. Incidence of injuries with or without a helmet needs to take into account the percentage of users that wear a helmet. At this juncture data indicate that both skiers and boarders that are wearing helmets and not wearing helmets get head injured. In a pilot observational study at Turoa ski area in 2010, 66% of skiers wore helmets. Estimates of the potential reduction in concussion are provided below. No international studies have reported a decline in overall head injury numbers associated with recent increased helmet use.

Head injury incidence - Of the 17,982 ski and snowboarding injuries recorded in the national incident data base (NID) utilised by all NZ commercial ski areas and managed by the NZ Mountain Safety Council (2005 to 2008), 2,048 (11.7%) were head injuries of which 877 were concussions (see Figures 1 to 7). There were twenty fatalities on mountains between 1st January 2008 to 8th Feb 2011 (9 climbing, 1 hunting, 2 heli-skiing, 1 ski-touring, 4 skiing, and 3 snowboarding).

Head injuries were 11.7% and other injuries were 88.3% for all skier and snowboarders injuries from 2005 to 2008 (see Figures 1 and 2). Of all 17,982 injuries (see Figure 3) only 4.9% were head concussions (see Figure 4). The number of skier and snowboarder concussion injuries increased from 2005 to 2007 with a slight decrease from 2007 to 2008 (see Figure 5). When looking at the percentage of concussions occurring with or without a helmet for skiers (see Figure 6), the range was 21-23% during 2005 to 2008, but there was an increase to 30% in 2008. These data make it look like there are more concussions occurring with helmets given the likely increase in helmet use from 2007 to 2008. The percentage increases in concussions with helmet use from 12% in 2005 to 23% in 2008 for snowboarders (see Figure 7) also makes it look like there are more concussions with helmet use. However, the percentage of snow participants that start a day skiing or snowboarding with or without a helmet (exposure or denominator data) needs to be taken into account to calculate injury odds ratios and hazard ratios. Concussion injuries occurred in 36 (15.9%) snow participants wearing a helmet and 190 (84.1%) not wearing a helmet during 2005 to 2008. If we take a value of 60% for participants wearing a helmet from our preliminary investigation of helmet use at Turoa in 2010, and the national average percentages for concussion injury for those with (15.9%) and without helmet (84.1%) use and calculate injury hazard ratios ($84/16 \div 40/60 = 7.9$), there is an approximately eight times increased risk of having a concussion injury for those not wearing a helmet. In practical terms, this means that if you had eight people in the ski area injury treatment room, and the hazard ratio was 7.9, seven of the eight people would not be there for concussion treatment if they had worn a helmet. Even if the percentage wearing a helmet was less at 30% rather than the 60% used in the calculation above, then there is still an approximately two times increased risk of having a concussion injury for those not wearing a helmet. Our calculations are only estimates given the helmet wearing percentage in non-injured skiers was collected in 2010, whilst injury data were collected from 2005 to 2009. These calculations only relate to concussion and not other types of head injuries.

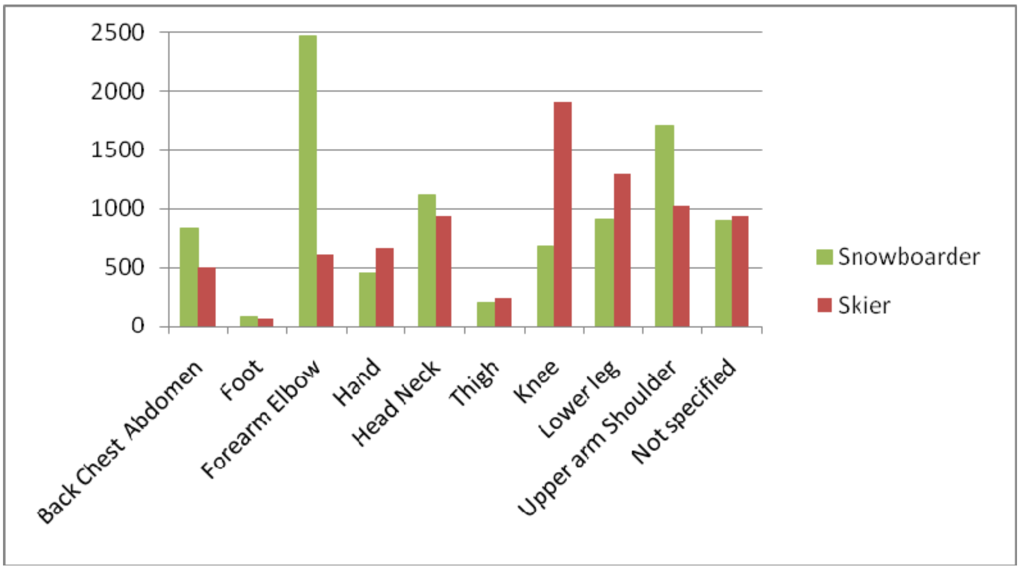

Figure 1: Frequency of body parts injured for skier and snowboarder total injuries from 2005 to 2008.

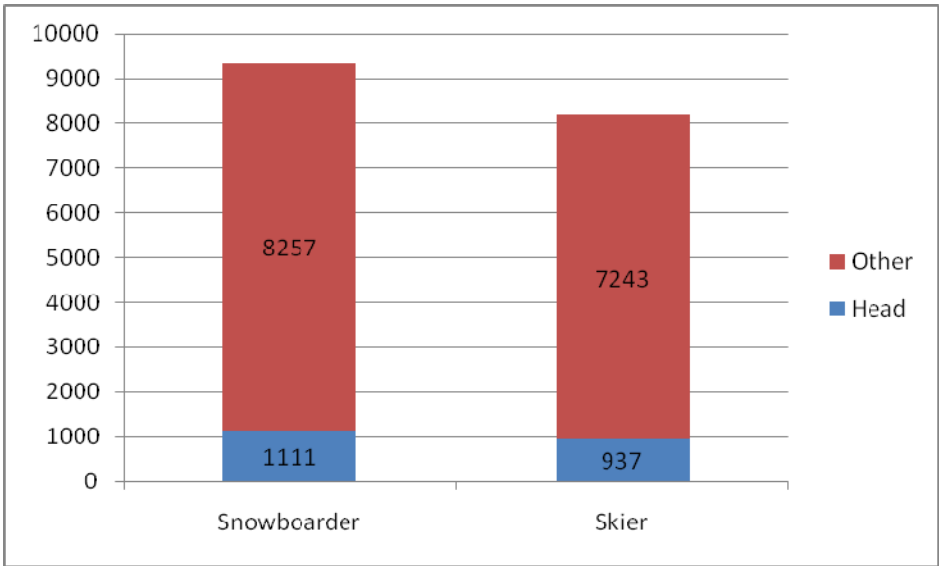

Figure 2: Frequency of head injuries and other injuries for skiers and snowboarders from 2005 to 2008.

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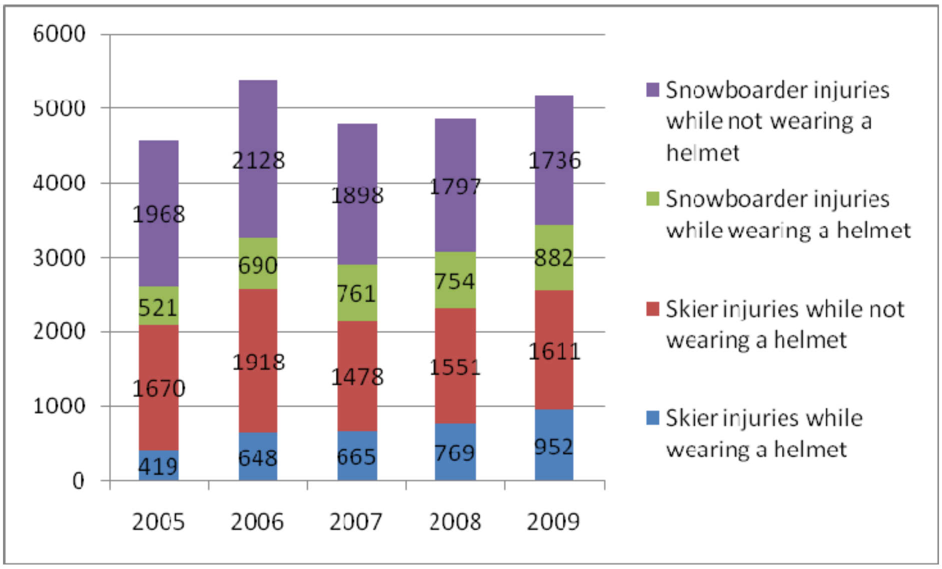

Figure 3: Number of skier and snowboarder total injuries with and without a helmet by year.

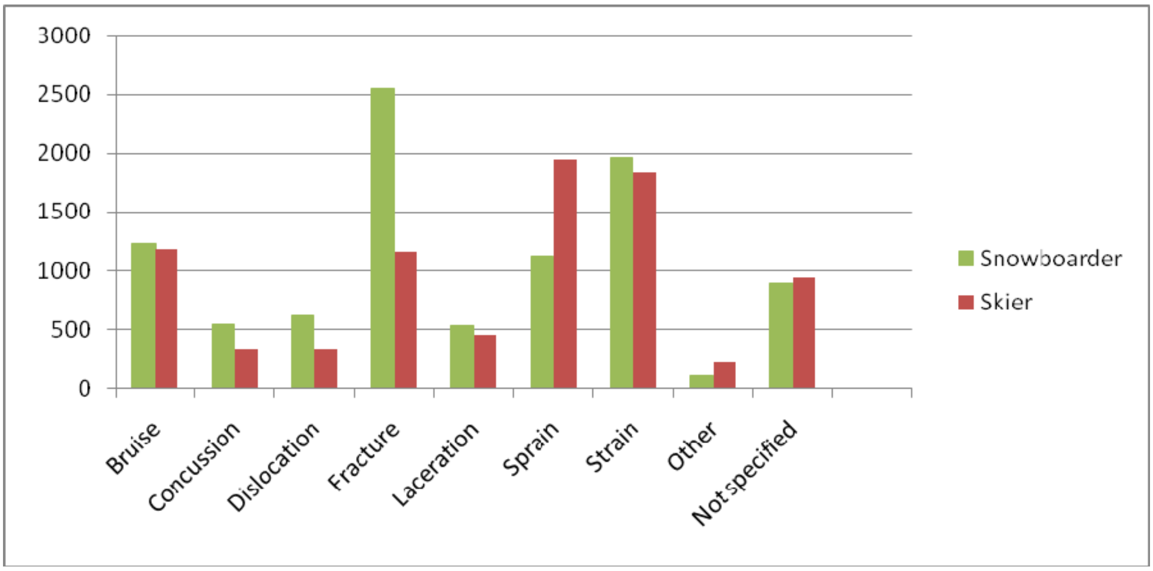

Figure 4: The number of injury types for skier and snowboarder total injuries from 2005 to 2008.

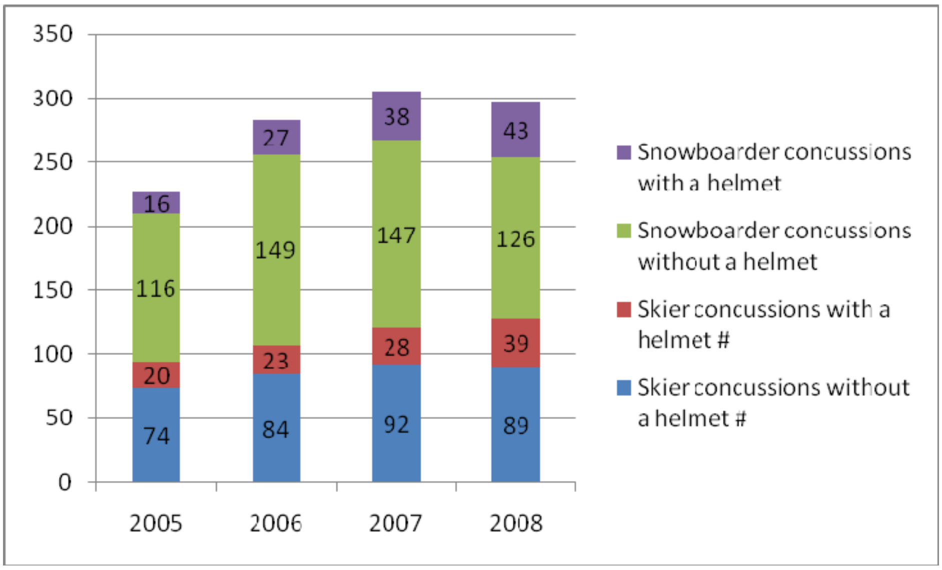

Figure 5: Number of skier and snowboarder concussion injuries with and without a helmet by year.

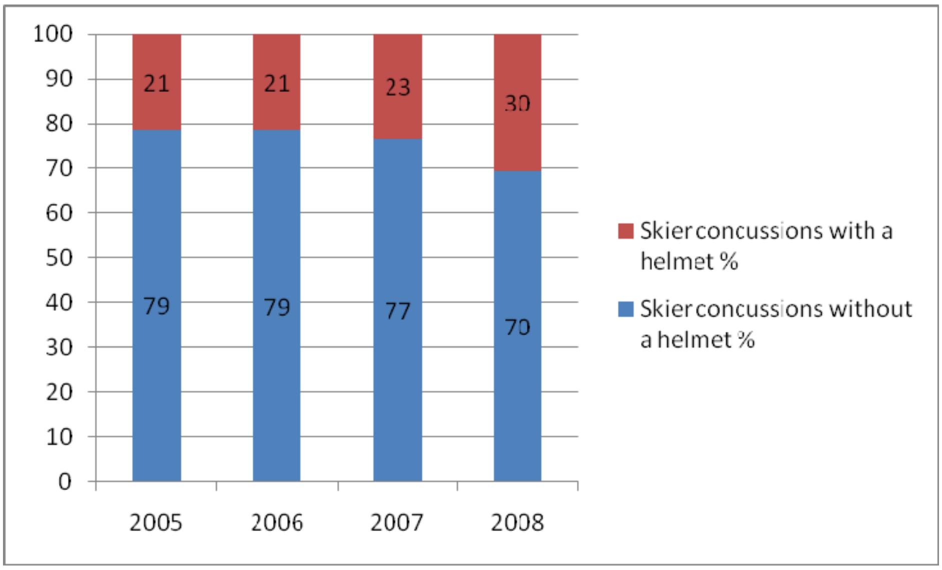

Figure 6: Percentage of skier concussion injuries with and without a helmet by year.

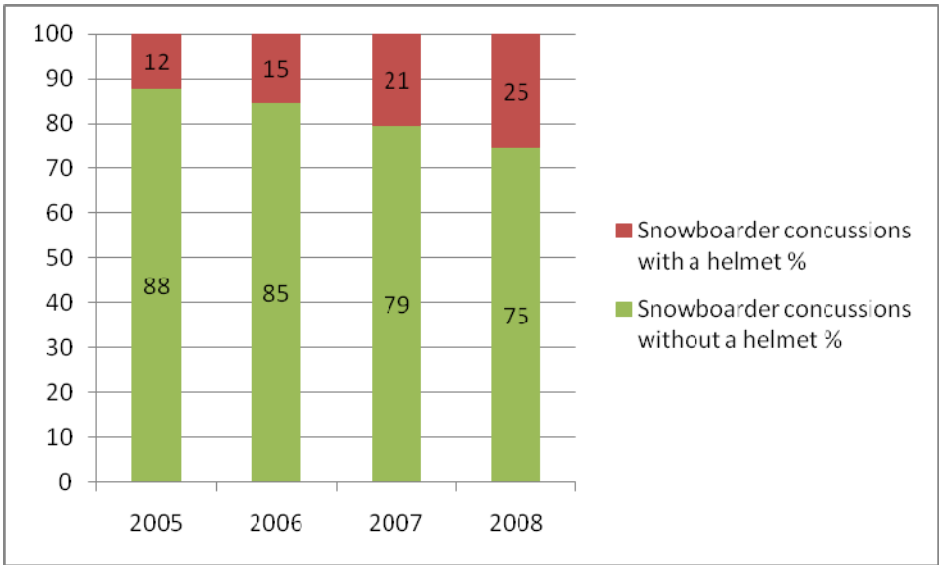

Figure 7: Percentage of snowboarder concussion injuries with and without a helmet by year.

Mechanisms - Both the literature review and analysis of free text in the ACC data based showed that the main mechanisms of head injury in alpine skiing and snowboarding [13] included falls (abrupt whole body falls onto the snow pack; twisting or compressing falls with transfer of force through lower limbs, to the pelvis, to the torso, neck and the head; falls from heights), collisions (with another skier or snowboarder; with an object), opposite-edge-phenomena (where snowboarders catch the downhill edge and the board rotates), phantom-foot mechanism (when there is deep knee flexion and internal lower leg rotation when the skier is off balance to the rear), non-release or inadvertent release from the ski-binding-boot system, contrecoup effect of sudden deceleration, and compressing and tumbling forces in avalanches. In non-New Zealand studies, high speed direct impact with a tree or falling in a tree-well were head injury mechanisms that frequently resulted in death [14].

Risk factors - Modifiable extrinsic risk factors include the environment and equipment. Modifiable intrinsic risk factors include skiing and snowboarder ability, risk taking behaviour, and physical conditioning.

Injury prevention strategies - Injury prevention is multi-factorial and as such requires a variety of strategies rather than a single strategy such as helmet use. Helmets may protect the skier or snowboarder from concussion but are not a panacea for all head injuries [7, Shealy, 2006 #679]. Impact to the head can be reduced by a helmet but it is entirely possible to overwhelm that degree of protection. Initial injury prevention should focus on primary injury prevention strategies that reduce the likelihood of head injury occurring (e.g., those interventions that reduce the risk of life threatening falls) followed by secondary strategies that reduce the magnitude of the effect of an injury (e.g., protective equipment). Perceived risk is often not related to actual risk, therefore, injury prevention strategies need to take this into account (e.g., slope selection). To prevent injury in alpine skiing and snowboarding an understanding of the skier responsibility code as with the road rules is paramount [15, 16].

Evidence that helmets reduce risk of injury - Although well designed studies are limited, helmet use may be associated with decreased risk of head injury. In a meta-analysis of 12 studies (10 case–control, one case–control/crossover and one cohort study), skiers and snowboarders who wore a helmet were 29–56% less likely than those who did not wear a helmet to have a head injury (odds ratio [OR] 0.65, 95% confidence interval [CI] 0.55–0.79). Studies that used controls without an injury showed similar odds ratios (OR 0.61, 95% CI 0.36–0.92), to those that used controls with an injury other than a head or neck injury (OR 0.63, 95%CI 0.52–0.80) and studies that included children under the age of 13 years (OR 0.41, 95%CI 0.27–0.59). Helmets were not associated with an increased risk of neck injury (OR 0.89, 95%CI 0.72–1.09) [17]. In one of the most well designed studies undertaken in Norway, there was a 60% reduction in head injury risk when wearing a helmet (OR 0.4; 95%CI 0.30–0.55) and risk of injury was higher in snowboarders than skiers (OR 1.53; 95%CI 1.22–1.91) [18]. In a 2008/2009 Austrian case control study helmet use was associated with a 28% reduction of head injury (OR: 0.72), head injury was more likely to occur in male versus female (1.43), involve collision versus fall (OR 4.15), in a snowpark versus on a slope (OR 1.69), occur during the morning versus the afternoon (OR 1.43), on a weekend versus a weekday (OR1.38) [19]. Children were two times more likely to sustain a head, face or neck injury than any other age group [20]. Helmets may dampen hearing capacity in frequencies 2–8 kHz so helmet wearers may misinterpret the sounds of potentially dangerous situations and increase their risk of injury [21]. Children and adults wearing helmets do not show greater risk taking behaviours but adolescence were found to continue high risk behaviour with or without a helmet when inline skating, skateboarding or snowboarding [22, 23].

In a study of modalities of death in the United States there was “no clear evidence that helmets have been shown to be an effective means of reducing fatalities in alpine sports” [7] p.137. Conversely, it has been reported that use of helmets “is prudent because it will reduce significantly the possibility of severe brain injury during head impacts, at the speed of a typical child skier” (p.100) [3].

Should helmets be mandatory? - Given that children are two times more likely to sustain head injuries than adults, New Zealand should consider the lead taken by European skiing and snowboarding countries and evaluate whether helmets should be mandatory for children aged less than 16 years [20]. The argument for mandatory helmets for adult skiers and snowboarders is countered by the argument for making informed choices to wear a helmet based on exposure to risks as not all conditions place a person at risk of injury [1, 15, 24]. Given the increased hazard ratios for receiving various types of head injury, such as concussion, when not wearing a helmet, helmet use should be encouraged [12, 15, 17, 18, 25].

To inform policy decisions further data collection is needed in to determine helmet wearing rates in alpine skiers and snowboarders in New Zealand. Injury hazard rates are then required to gain an accurate picture of the protective effect of helmets for different types of head injury, and different types of injury mechanisms.

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